# OPTIMIZATION DESIGN OF AXIAL FLOW COMPRESSOR

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## ABSTRACT

*An axial compressor is a pressure producing machine. It is a rotating, airfoil-based compressor in which the working fluid principally flows parallel to the axis of rotation. This is in contrast with other rotating compressors such as centrifugal compressors, axi-centrifugal compressors and mixed-flow compressors where the air may enter axially but will have a significant radial component on exit. The energy level of air or gas flowing through it is increased by the action of the rotor blades which exert torque on the fluid which is supplied by an electric motor or a steam or a gas turbine. In this thesis, an axial flow compressor is designed and modeled in 3D modeling software SOLIDWORKS. The present design has 30blades, in this thesis it is replaced with 10 blades. The present used material is Alloy Steel; it is replaced with chromium alloy and Tungsten alloy. Structural analysis is done on the compressor models to verify the strength of the compressor. CFD analysis is done to verify the flow of air. The stress values are less for Tungsten alloy than the respective yield stress values for Chromium steel and Alloy steel. The stress value is less for Tungsten alloy than Chromium steel and Alloy steel, so using Tungsten alloy is better. By using 10blades the stresses are increasing, but are within the limits. CFD analysis is done to verify the flow of air. The outlet velocity is increasing for 10 blades; pressure is more for 30 blades. So it concluded that using Tungsten alloy and 10 blades is better for compressor blade.*

**Keyword**: **-** *Optimized Design , Axial flow Compressor , Blade,3D Solid Works , CFD Analysis.*

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## 1. INTRODUCTION

A Compressor is a fluid handling mechanical device capable of efficiently transferring Energy to the fluid medium so that it can be delivered in large quantities at elevated pressure Conditions. Compressors have numerous applications ranging from aircraft and process industries to household appliances such as refrigerators and air conditioners. Compressors are generally Categorized by their volumetric size, which in turn determines the area of application. Centrifugal Compressors are widely used for volumetric flow rates of 0.45 m3 / s to4.5 m3 / s. Multi stage axial Compressors are often preferred for larger volumetric sizes. Pressure ratios as high as 12 have been Recorded for a single centrifugal stage, whereas axial systems generally reach pressure ratios up to 2 per stage.

**1.2 TYPES OF COMPRESSORS:**

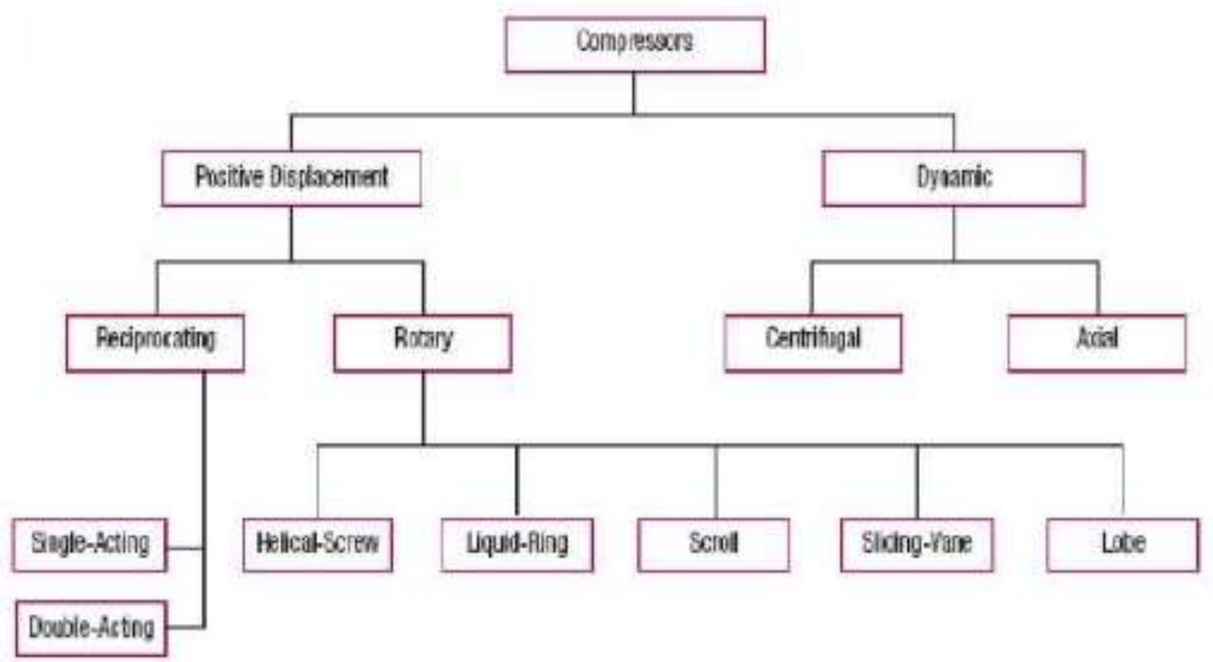



**Fig 1.1 Types of compressors**

Positive displacements machines work by mechanically changing volume of the working fluid. Dynamic machines work by mechanically changing the velocity of the working.

## AXIALCOMPRESSOR

An **axial compressor** is a machine that can continuously pressurize gases. It is a rotating, airfoil- based compressor in which the gas or working fluid principally flows parallel to the axis of rotation. This differs from other rotating compressors such as centrifugal compressors, axi-centrifugal compressors and mixed-flow compressors where the fluid flow will include a "radial component" through the compressor. The energy level of the fluid increases as it flows through the compressor due to the action of the rotor blades which exert a torque on the fluid. The stationary blades slow the fluid, converting the circumferential component of flow into pressure. Compressors are typically driven by an electric motor or a steam or a gas turbine. Axial flow compressors produce a continuous flow of compressed gas, and have the benefits of high efficiency and large mass flow rate, particularly in relation to their size and cross-section. They do, however, require several rows of airfoils to achieve a large pressure rise, making them complex and expensive relative to other designs (e.g. centrifugal compressors).

Axial compressors are integral to the design of large gas turbines such as jet engines, high speed ship engines, and small scale power stations. They are also used in industrial applications such as large volume air separation plants, furnace air, fluid catalytic cracking air, and propane dehydrogenation. Due to high performance, high reliability and flexible operation during the flight envelope, they are also used in aerospace engines.

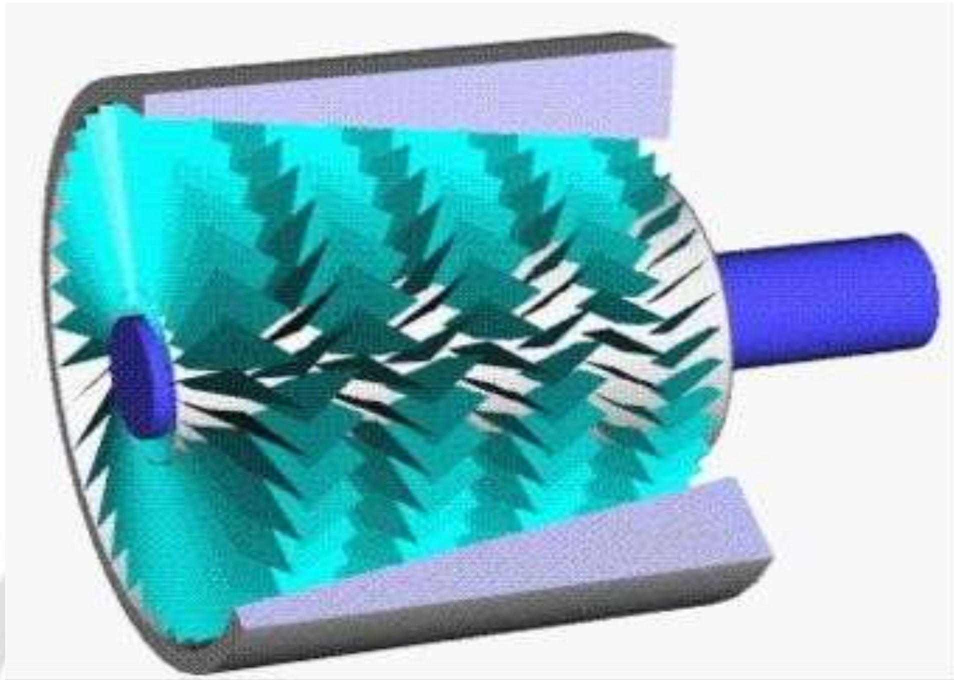


**Fig 1.7 Axial compressors**

## DESCRIPTION

Axial compressors consist of rotating and stationary components. A shaft drives a central drum, retained by bearings, which has a number of annular airfoil rows attached usually in pairs, one rotating and one stationary attached to a stationary tubular casing. A pair of rotating and stationary airfoils is called a stage. The rotating airfoils, also known as blades or rotors, accelerate the fluid. The stationary airfoils, also known as stators or vanes, convert the increased rotational kinetic energy into static pressure through diffusion and redirect the flow direction of the fluid, preparing it for the rotor blades of the next stage.[3] The cross-sectional area between rotor drum and casing is reduced in the flow direction to maintain an optimum Mach number using variable geometry as the fluid is compressed.

## WORKING

As the fluid enters and leaves in the axial direction, the centrifugal component in the energy equation does not come into play. Here the compression is fully based on diffusing action of the passages. The diffusing action in stator converts absolute kinetic head of the fluid into rise in

pressure. The relative kinetic head in the energy equation is a term that exists only because of the rotation of the rotor. The rotor reduces the relative kinetic head of the fluid and adds it to the absolute kinetic head of the fluid i.e., the impact of the rotor on the fluid particles increases its velocity (absolute) and thereby reduces the relative velocity between the fluid and the rotor. In short, the rotor increases the absolute velocity of the fluid and the stator converts this into pressure rise. Designing the rotor passage with a diffusing capability can produce a pressure rise in addition to its normal functioning. This produces greater pressure rise per stage which constitutes a stator and a rotor together. This is the reaction principle in turbo machines. If 50% of the pressure rise in a stage is obtained at the rotor section, it is said to have a 50% reaction.

## DESIGN:

The increase in pressure produced by a single stage is limited by the relative velocity between the rotor and the fluid, and the turning and diffusion capabilities of the airfoils. A typical stage in a commercial compressor will produce a pressure increase of between 15% and 60% (pressure ratios of 1.15–1.6) at design conditions with a polytrophic efficiency in the region of 90– 95%. To achieve different pressure ratios, axial compressors are designed with different numbers of stages and rotational speeds. As a general rule-of-thumb we can assume that each stage in a given compressor has the same temperature rise (Delta T). Therefore, at the entry, temperature (Tstage) to each stage must increase progressively through the compressor and the ratio (Delta T)/(Tstage) entry must decrease, thus implying a progressive reduction in stage pressure ratio through the unit. Hence the rear stage develops a significantly lower pressure ratio than the first stage. Higher stage pressure ratios are also possible if the relative velocity between fluid and rotors is supersonic, but this is achieved at the expense of efficiency and operability. Such compressors, with stage pressure ratios of over 2, are only used where minimizing the compressor size, weight or complexity is critical, such as in military jets. The airfoil profiles are optimized and matched for specific velocities and turning. Although compressors can be run at other conditions with different flows, speeds, or pressure ratios, this can result in an efficiency penalty or even a partial or complete breakdown in flow (known as compressor stall and pressure surge respectively). Thus, a practical limit on the number of stages, and the overall pressure ratio, comes from the interaction of the different stages when required to work away from the design conditions. These "off-design" conditions can be mitigated to a certain extent by providing some flexibility in the compressor.

This is achieved normally through the use of adjustable stators or with valves that can bleed fluid from the main flow between stages (inter-stage bleed). Modern jet engines use a series of compressors, running at different speeds; to supply air at around 40:1 pressure ratio for combustion with sufficient flexibility for all flight conditions.

**CFD ANALYSIS RESULTS FOR 30 BLADES COMPRESSOR**:

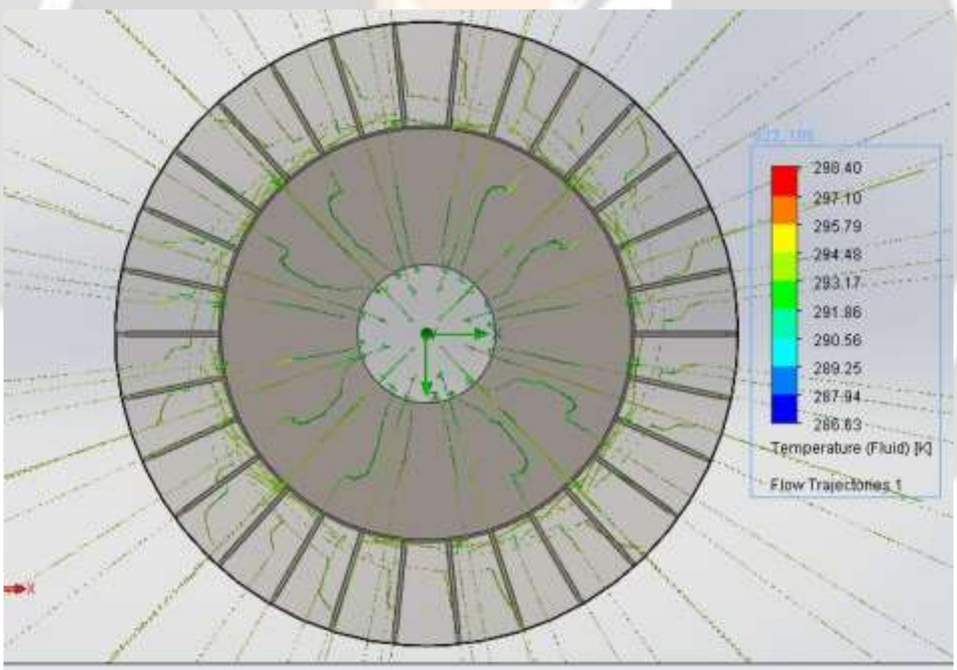



**Figure 7.2.1: Temperature**

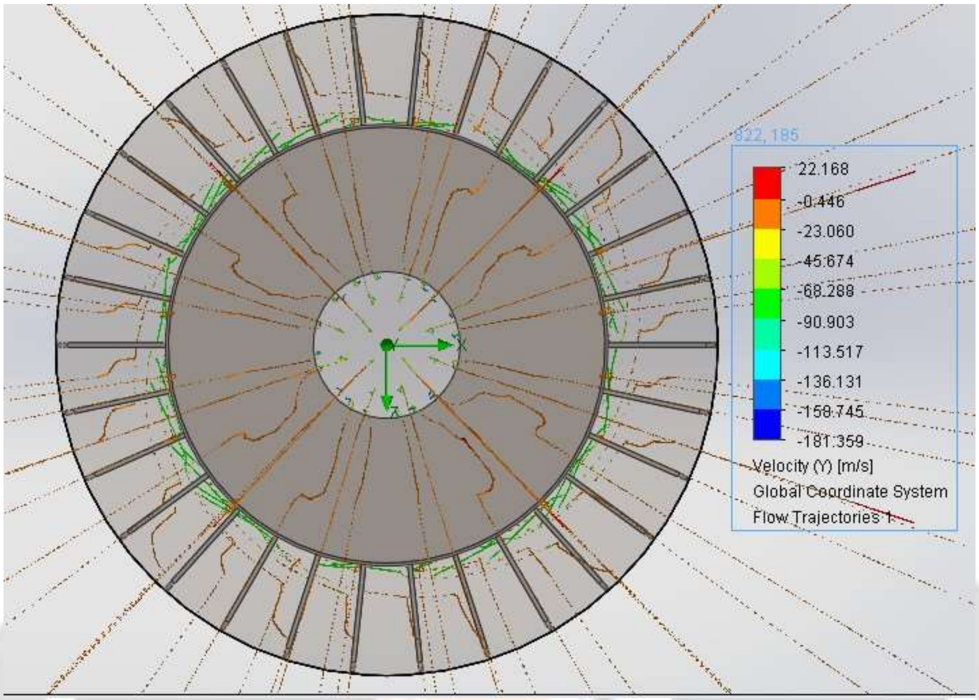



**Figure 7.2.2 Velocity magnitude**

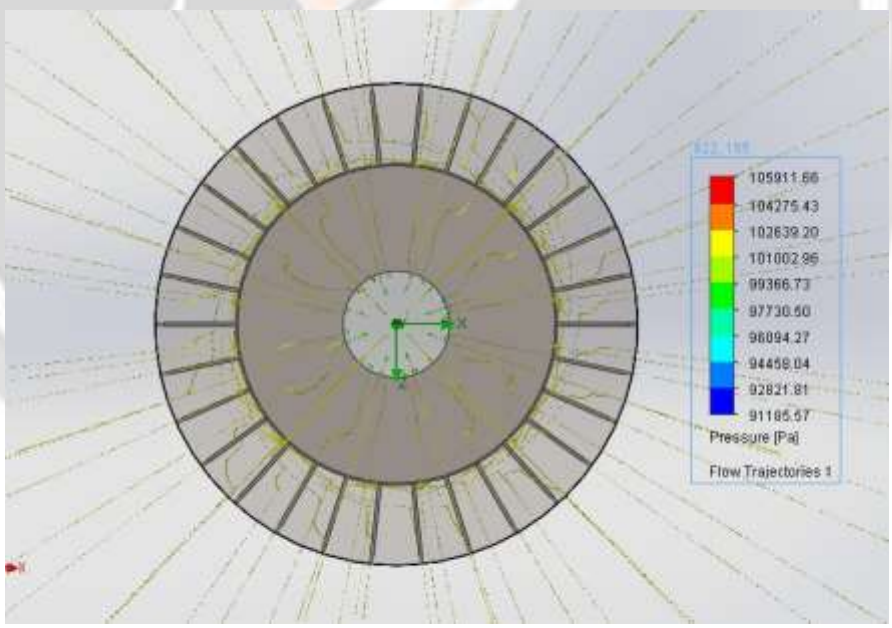
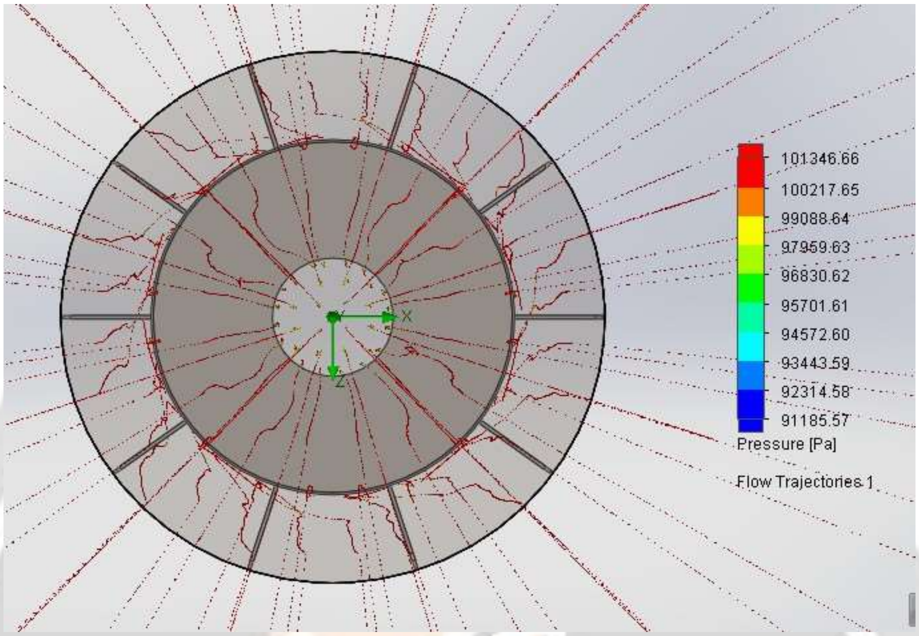



**Figure 7.2.3 Static Pressure**

**RESULTS FOR 10 BLADE COMPRESSORS**

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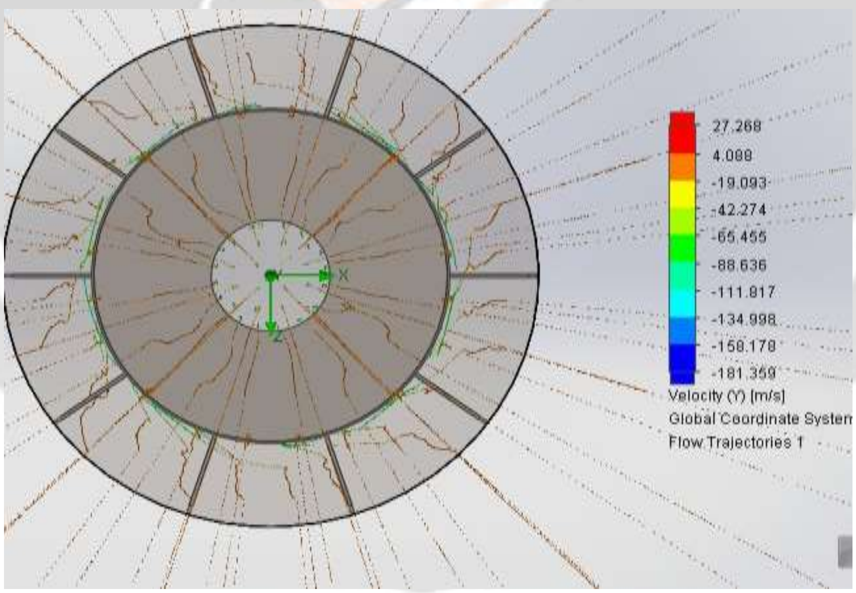


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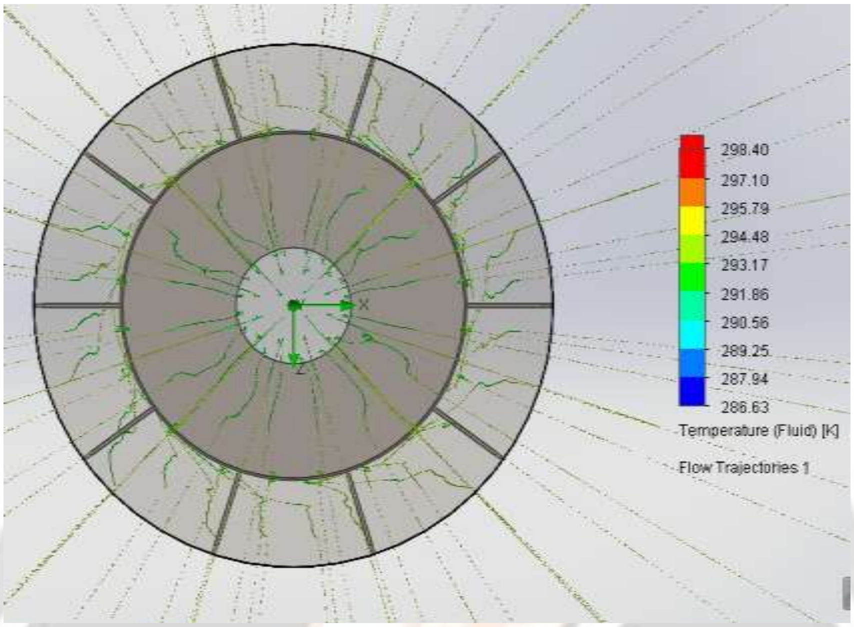


**Figure 7.3 Temperature**

## RESULTS AND DISCUSSIONS

MAIN FEATUERS FOR 30 BLADES:

| S.NO | MATERIAL | VON Misses Stress( Mpa) | Displacement (mm) | Strain |
|---|---|---|---|---|
| **1.** | **ALLOY STEEL** | **18.596** | **0.054** | **6.96485e-005** |
| **2.** | **CHROMIUM STEEL** | **26.578** | **0.056939** | **7.3131e-005** |
| **3.** | **TUNGSTEN ALLOY** | **13.675** | **0.0918371** | **0.000117953** |

**Table 8.1 30 BLADES**

FOR 10 BLADES:

| S.NO | MATERIAL | VON Misses Stress( Mpa) | Displacement (mm) | Strain |
|---|---|---|---|---|
| 1. | ALLOY STEEL | 17.8456 | 0.0329776 | 7.04772e-005 |
| 2. | CHROMIUM STEEL | 26.5 | 0.0346265 | 7.4001e-005 |
| 3. | TUNGSTEN ALLOY | 13.365 | 0.0558492 | 0.000119357 |

**Table 8.2 10 BLADES**

**CFD RESULTS:**

| S.NO | RESULTS | 30 blades | 10 blades |
|---|---|---|---|
| 1. | Velocity (m/s) | 22.1 | 27.268 |
| 2. | Pressure(Pa) | 105911.66 | 101246.66 |
| 3. | Temperature(k) | 298.4 | 298.4 |

**Table 8.3 CFD Result**

## CONCLUSIONS:

An axial compressor is a pressure producing machine. It is a rotating, airfoil-based compressor in which the working fluid principally flows parallel to the axis of rotation. This is in contrast with other rotating compressors such as centrifugal compressors, axi-centrifugal compressors and mixed-flow compressors where the air may enter axially but will have a significant radial component on exit. The energy level of air or gas flowing through it is increased by the action of the rotor blades which exert a torque on the fluid which is supplied by an electric motor or a steam or a gas turbine.

In this Project, an axial flow compressor is designed and modeled in 3D modeling software SOLIDWORKS. The present design has 30 blades, in this thesis it is replaced with 10 blades. The present used material is chromium steel ; it is replaced with Alloy steel and tungsten alloy .Alloy steel are high strength materials than Chromium Steel. The density of Tungsten alloy is less than that of Chromium Steel and Alloy steel. So using Titanium alloy for compressor blade decreases the weight of the compressor Structural analysis is done on the compressor models to verify the strength of the compressor. The stress values are less for Tungsten alloy than the respective yield stress values for Chromium steel and Alloy steel. The stress value is less for Tungsten alloy than Chromium steel and Alloy steel, so using Tungsten alloy is better. By using 10 blades the stresses are increasing, but are within the limits. CFD analysis is done to verify the flow of air. The outlet velocity is increasing for 10 blades; pressure is more for 30 blades. So it concluded that using Tungsten alloy and 10 blades is better for compressor blade.

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## [5] BIOGRAPHIES

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